SAGE III Aerosol Extinction Measurements: Initial Results

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Abstract. Beginning in February 2002, the Stratospheric Aerosol and Gas Experiment III (SAGE III) has been producing aerosol extinction profiles in the upper troposphere and stratosphere at nine wavelengths between 384 and 1545 nm. An initial examination of the data quality has found that the data agree well with coincident measurements by SAGE II and the shape of the aerosol spectra suggests that the measurement ensemble is consistent across most wavelengths. A problem, probably associated with ozone cross sections, creates small bias at 755 nm and possibly 869 nm. The channel at 601 nm is noisy due to strong ozone absorption and is produced mostly as a tool for tracking ozone data quality.

1. Introduction

The Stratospheric Aerosol and Gas Experiment (SAGE III) was launched into a sun-synchronous orbit aboard the Russian Meteor 3M platform in December 2001 and began routine operations on 27 February 2002. Like its predecessor instruments, summarized in Table 1, SAGE III uses solar occultation to infer vertical profiles of ozone, nitrogen dioxide, water vapor, and multi-wavelength aerosol extinction from the mid-troposphere into the mesosphere. New in this series of instruments, SAGE III makes measurements of the oxygen A-band (758-771 nm) from which profiles of temperature and pressure are derived. It also adds a lunar occultation mode in which profiles of ozone, nitrogen dioxide, nitrogen trioxide, and chlorine dioxide are derived and an experimental limb scatter mode that may produce archived data in the future.

The solar measurement strategy has remained essentially unchanged from that used by SAGE II. During each sunrise and sunset encountered by the platform, the instrument scans across the Sun vertically relative to the Earth's surface. The orbital characteristics of the Meteor 3M platform dictate measurement locations which occur in high northern latitudes (45-80N) for platform sunsets and southern mid-latitudes (25-60S) for platform sunrises. Measurements made along paths above the Earth's atmosphere are used to normalize the data to profiles of line-of-sight transmission. Variations in the multi-wavelength transmission data are used to separate the contributions of gas species and aerosol. The hardware configuration of the SAGE III instrument [Thomason et al., 1999] is significantly different from either SAGE or SAGE II. Instead of a handful of channels (e.g., seven for SAGE II), SAGE III provides 87 channels distributed between 285 and 1545 nm to infer the target species. The additional channels are chosen to provide better characterization of gas absorption features while concomitantly reducing the sensitivity of their retrieval to the presence of enhanced aerosol associated with either cloud or volcanic eruptions. The sensitivity of SAGE II measurements of ozone and water vapor to enhanced aerosol is well documented [e.g., Wang et al., 2002]. The added channels allow the use of an algorithm that uses a multi-linear regression technique that is much less sensitive to the presence of smoothly varying components like aerosol to separate the effects of gas species absorption from aerosol extinction. This is in contrast to the interpolative approach required for previous instruments [e.g., Chu et al., 1989]. In the new approach, the aerosol product is produced as a residual following the removal of the effects of ozone and other species. The SAGE III algorithms are described in detail in the *SAGE III Algorithm Theoretical Basis Document: Solar and Lunar Algorithm* [2002] that is available from the Earth Observing System Project science Office web site (http://eospso.gsfc.nasa.gov).

The first public release of SAGE III data (Version 2) took place in December 2002 and is comprised of data dating from 7 May 2002 and continuing thereafter. Herein, the aerosol data contained in that release is described and a preliminary comparison with coincident SAGE II data is made.

2. SAGE III Aerosol Extinction Measurements

Figure 1 shows the variation in the daily median northern hemisphere aerosol extinction profile at 1022 nm from 1 June 2002 through 31 January 2003. Characteristic of a relatively quiescent period, the overall variations during this period are small and primarily driven by the slow variations in the latitude of these measurements. For instance, the strong gradient between the clean stratosphere and the hazier troposphere moves from around 12 km in the summertime mid-latitudes to around 7 km during the Arctic winter, essentially tracking the change in the height of the tropopause. Within the stratosphere, the contours of aerosol extinction likewise vary smoothly through 2002. After the start of 2003, some significant variations are obvious above about 15 km. These variations have been frequently observed in the SAGE II data and are related to episodic transport from lower latitudes that is most frequently observed during winter [Trepte and Hitchman, 1992]. Below 15 km, there is a gradual increase in aerosol extinction beginning in late November 2002 that continues through the end of January 2003 and forms a diffuse layer around 11 km by the end of this period. It is possible that this aerosol is from a tropical event, likely of volcanic origin, first noted around 20 km in the SAGE II observations between the 20th and 22nd of October 2002 at the equator to 20ºN. The development of this layer in the tropics is summarized in Figure 2. The most likely candidate is an eruption by Tungurahua on October 2nd though the plume height was reported at only 14.3 km (GVN, 2002). The eruption by Reventador, with a reported plume height of 20 km, is too late (November 3rd) to have caused the perturbation measured by SAGE II but may play a role in the enhancement at high latitudes.

Polar stratospheric clouds (PSCs) have been observed in the SAGE III observations in both the Northern and Southern hemispheres. PSCs were noted in the south beginning in late June with occasional observations extending to mid-August. Figure 3 shows a PSC observed on 7 July 2002 where the extinction enhancement was nearly a factor of 100 over the vortex background. In the north, PSCs appear in early December and are frequent in January 2003. Since PSCs have a limited longitudinal distribution, the daily median filter used to produce Figure 1 is effective at suppressing their effects. Another significant feature of the PSC profile in Figure 3 is the gaps that appear above 25 km. Unlike SAGE II, there is currently no smoothing of the line-of-sight profiles of SAGE III products prior to being reduced to the vertical profile though this may be included in a future release. As a result, SAGE III profiles at high altitudes are typically noisier and have more data dropouts than equivalent profiles from SAGE II.

Figure 4 shows the daily median aerosol spectra in the northern hemisphere on 20 December 2002. The spectra show several features that are characteristic of this release of SAGE III data. As would be expected, aerosol extinction decreases with increasing wavelength following a relationship that could be approximately represented by a power law or Angstrom coefficient. At shorter wavelengths, there is some indication that the spectra flatten somewhat at higher extinction levels. This is typical of stratospheric aerosol due to their size distribution and optical properties [Russell et al., 1994].

The channel located at 601 nm frequently does not fit into this pattern and consistently is the noisiest channel in the aerosol ensemble. Since ozone absorbs strongly at this wavelength and aerosol extinction is only a small fraction of the total optical depth measured at this wavelength, this result was not unexpected. It is included in the set primarily for its value in the quality assessment of the aerosol and ozone observations and for possibly providing insight into clearing aerosol from SAGE and SAGE II data. Another feature commonly appearing in the spectra is a weak maximum in aerosol extinction at 755 nm at all altitudes. We have found that increasing the ozone cross section at this wavelength by ~10% greatly reduces or eliminates the presence of this peak. At the same time, the change in cross section improves the temperature/pressure retrieval based on A Band absorption (759-771 nm) that is dependent primarily on the 755-nm aerosol channel for clearing the effects of aerosol extinction at these wavelengths. As a result, we believe that the maximum at this wavelength is an artifact of the incomplete clearing of ozone. There is a similar but smaller, oppositely signed bias in the 869-nm aerosol data that appears only above 24 km. Both the 755 and 869-nm aerosol channels are located near minima in the ozone Wulf band structure with cross sections that are less than the peak of the Chappuis by factors of about of 20 and 100, respectively. At stratospheric temperatures, ozone cross sections at these wavelengths are suspect and, in fact, the current SAGE III ozone spectroscopy data set has no temperature dependence at all at 869 nm [Shettle and Anderson, 1995]. As a result, we are pursuing an improved ozone spectroscopic database and we advise caution using the 601, 755, and 869 nm aerosol channels in this release of the data.

The validation of the aerosol products is an ongoing process that will be reported in future publications. These activities include an extended field campaign based out of Kiruna, Sweden in January and February 2003 called the SAGE III Ozone Loss and Validation Experiment (SOLVE II). In addition, comparisons of SAGE III products with in situ, ground-based and other satellite-based observations represent a key element of establishing the vigor of the new data set. Figure 5 shows the comparison of a single coincidence between SAGE II and SAGE III that occurred on 14 September 2002 in which the events occurred 128 km and 3 minutes apart. With only minor wavelength differences, four of the SAGE III channels can be compared with the SAGE II data: 384 vs. 386 nm, 449 vs. 452 nm, 520 vs. 525 nm, and 1022 vs. 1019 nm, respectively. In the primary stratospheric aerosol layer between 12 and 23 km, the mean relative errors are close to zero for the three shorter wavelength comparisons whereas the SAGE III observations average about 15% less than SAGE II at 1019 nm. It is not clear what causes the differences between the long wavelength channels and further validation work is required. The agreement below 10 km is not as favorable but the large relative differences are the result of clouds that are observed below 8.5 km by SAGE II but below 9.5 km by SAGE III.

3. Conclusions

SAGE III aerosol extinction measurements, publicly available since December 2002, show considerable promise as the continuation and extension of the SAGE II data set. An initial examination of the data suggests that most of the data is of reasonable quality though substantial validation work is yet to be completed. In the meantime, we suggest that users apply caution using channels located at 601 and 755 nm and the 869-nm channel above 24 km in the Version 2 release.

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Table 1. SAGE III and its predecessor instruments aerosol measurement characteristics

Instrument	Operational Period	Latitude Coverage	Aerosol Extinction Channel Locations
SAM II	1978-1993	60-80N, 60-80S	1000 nm
SAGE	1979-1981	70S-70N	385, 450, 1000 nm
SAGE II	1984-present	80S-80N	386, 452, 525, 1019 nm
SAGE III	2002-present	45-80N, 25-60S	384, 449, 520, 601, 676, 755, 869, 1022, 1545 nm

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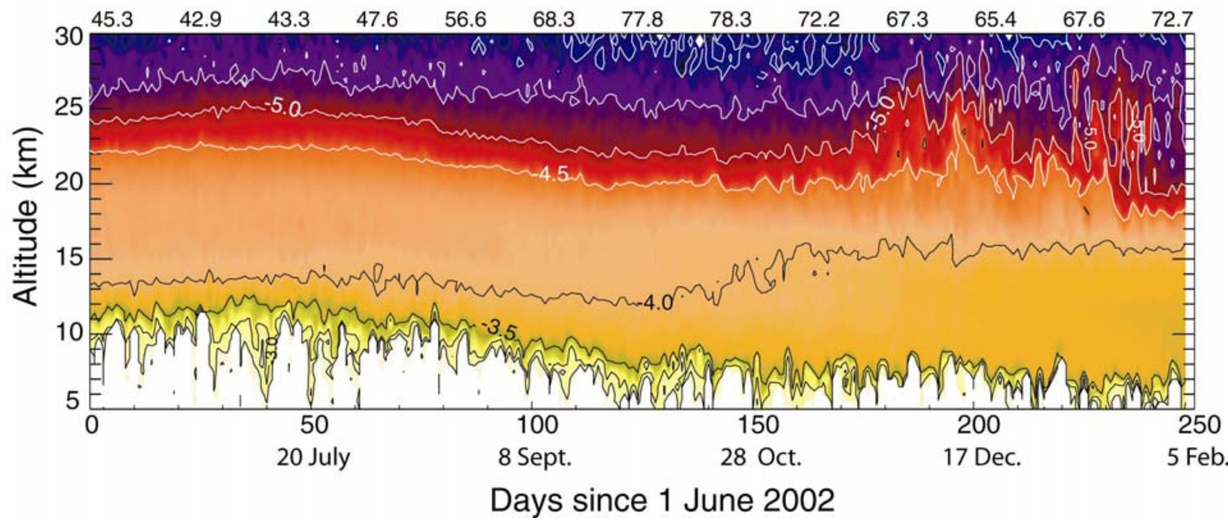

Figure 1. This figure depicts the median daily northern hemisphere SAGE III 1022-nm aerosol extinction from 1 June 2002 to 8 February 2003. The mean latitude as a function of time is annotated across the top of the plot.

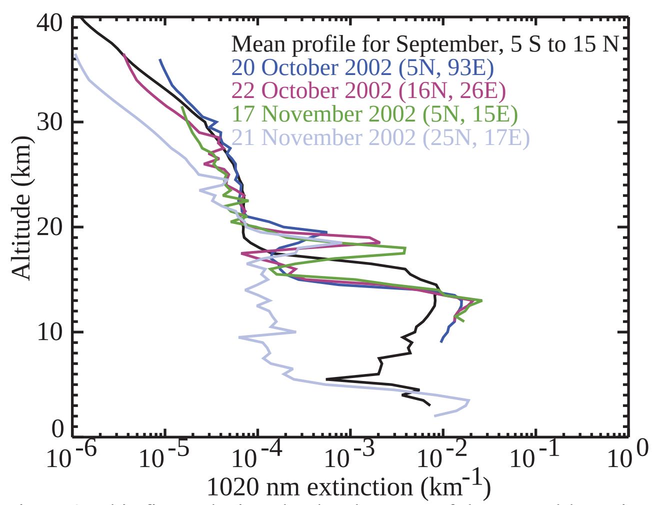

Figure 2. This figure depicts the development of the aerosol layer in the tropical stratosphere as seen by SAGE II. The September profile is a daily average while the October and November data are individual profiles that show strong effects from a recent volcanic event.

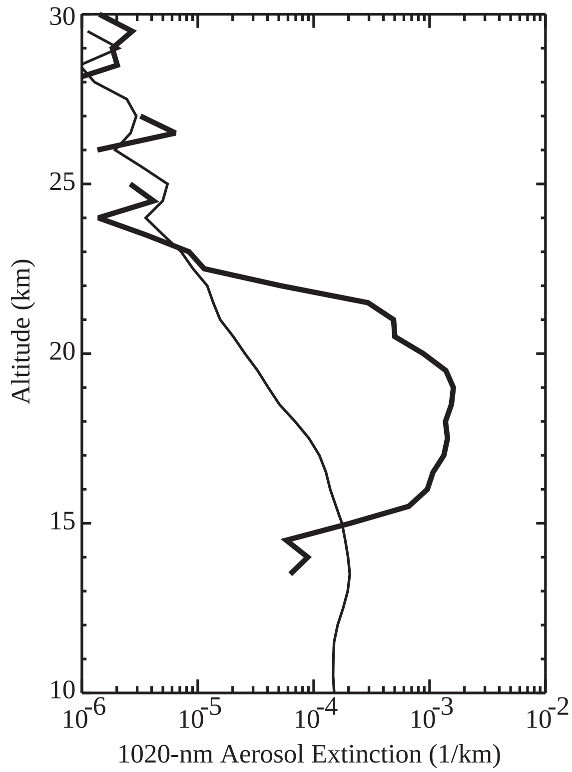

Figure 3. This figure depicts an aerosol extinction profile from 7 July 2002 with a polar stratospheric cloud between 15 and 23 km (thick line) in the southern hemisphere (56S, 46W). The thin line is the average of 3 profiles within the polar vortex but no PSCs.

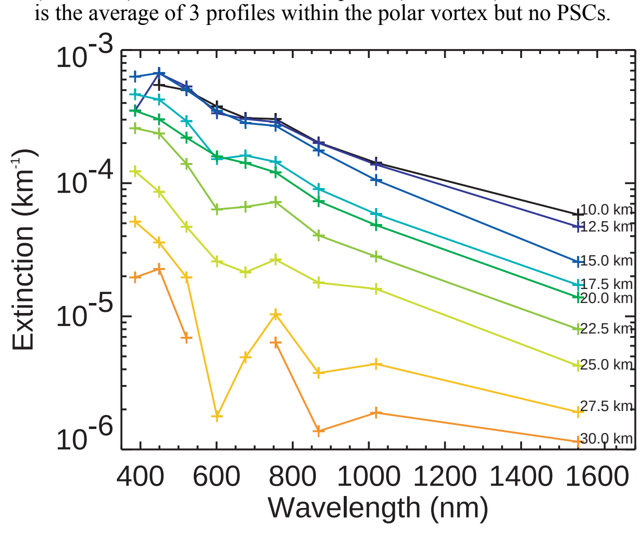

Figure 4. This figure depicts the SAGE III-measured aerosol extinction spectra at nine wavelengths averaged for 20 December 2002.

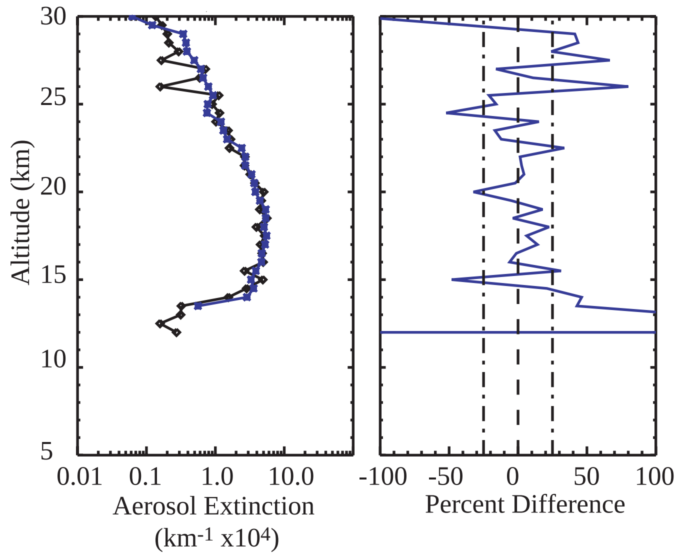

Figure 5(a). This figure depicts the results of a comparison of SAGE III (blue) and SAGE II (black) aerosol extinction on 14 September 2002 at 384 nm. The difference is given as 100.*(SAGE III-SAGE II)/SAGE III.

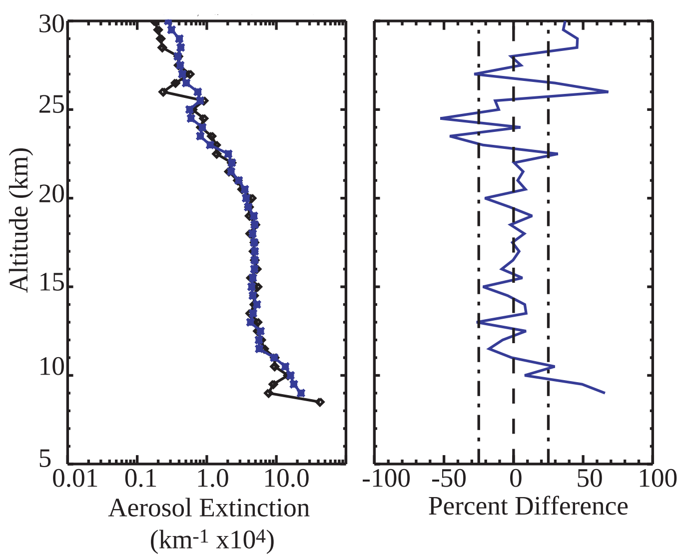

Figure 5(b). Same as Figure 4(a) except for aerosol extinction at 449 nm.

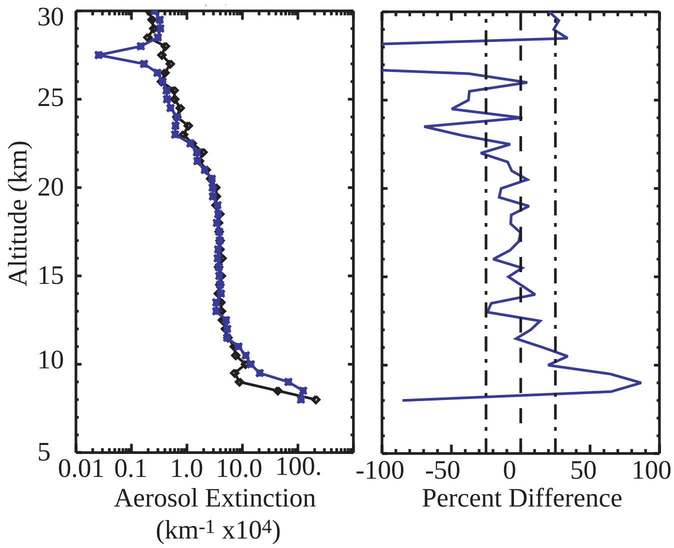

Figure 5(c). Same as Figure 4(a) except for aerosol extinction at 520 nm.

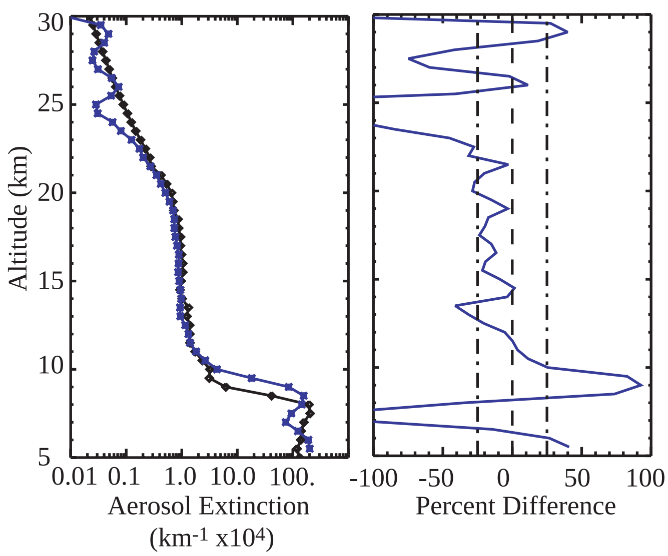

Figure 5(d). Same as Figure 4(a) except for aerosol extinction at 1022 nm.